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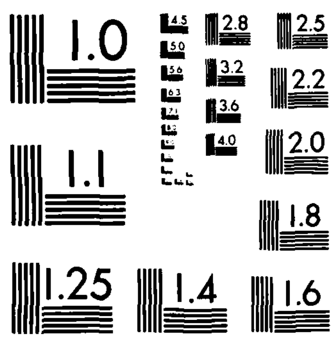


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Research Report CCS 493

# FOOD SELF-SUFFICIENCY INVESTMENTS IN THE MIDDLE EAST

by

A. Al-Saffar
A. Charnes
S. Duffuaa*

**CENTER FOR CYBERNETIC STUDIES**
The University of Texas
Austin, Texas 78712

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*University of Petroleum and Minerals, Dhahran, Saudi Arabia

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CENTER FOR CYBERNETIC STUDIES

A. Charnes, Director
College of Business Administration, CBA 5.202
The University of Texas at Austin
Austin, Texas 78712
(512) 471-1821

FOOD SELF-SUFFICIENCY INVESTMENTS

IN THE MIDDLE EAST


## Abstract

This study proposes a dynamic goal programming model for planning joint investment in agriculture to achieve self-sufficiency in food production in the Middle East.

The issue of equitable allocation of returns to participants in the joint investments is addressed as well. Equitable divisions of profits and equitable assessment of costs to collaborating investors are developed through an associated characteristic function game.





Key Words

Dynamic Goal Programming

Game Theory

## 1.0 Introduction

Many previous studies have examined the possibility of the countries in the Middle East being self-sufficient in major food items. In [9,12] it was concluded that self-sufficiency is feasible provided there is cooperation between countries which have complementary economic sectors. For example, the Sudan is a vast country with plenty of land, labor and water, whereas Kuwait, Saudi Arabia and Abu Dhabi have vast supplies of capital. The conditions for attaining self-sufficiency in the Middle East include (10,11):

1) good management of identified projects,
2) flow of cash from oil-producing countries,
3) modernization of the agricultural sector without disruption of the old technologies.

The studies in [9,12], however, ignore important concerns such as identifying feasible agricultural projects or industrial projects related to agriculture. None of the studies have produced a production plan to achieve food self-sufficiency, nor do they suggest mechanisms, or a set of decisions or guidelines to initiate such a process of cooperation. Most of the studies do concentrate on the huge demand for food in the Middle East and the potential of the Sudan for meeting that demand. Also important if a cooperation process is to start is a proper equitable division of the returns on these projects and, indeed, whether or not all participants would gain in joining a project.

In this paper we shall attempt to address these concerns by means of an input-output dynamic goal programming model . The model will determine among other things how much and which inputs are needed to attain desired goals in food production.

To address the question of equitable allocation of the returns on these projects, which is uncertain or random, we synthesize a game in chance-constrained characterastic function form from the optimal solution to our goal programming model. A proposed new solution for this chance-constrained game gives us a proportional distribution for the random return. This solution is an extension of the homocore or monocore concept (7,8) to the chance-constrained game.

In section 2 we will present the demand and supply side of food in the Middle East and develop our goals to be used in the model. In section 3 we present our goal programming approach to this situation and discuss its suitability. In section 4 we present a prototype model. In section 5 we present the game-theoretic methodology for allocating the "random harvest." Section 6 presents and discusses a numerical example with the conclusion.

## 2.0 Demand and Supply Side

This section will consider the demand for food items which seem worthwhile for inclusion in our model. Also to be examined are the supply and availability of land, water and labor in the Middle East. By Middle East, we shall mean the countries of north Africa and southwest Asia.

### 2.1 Demand Side

In [12 ] the demand side of most items in the Middle East diet were examined, and the factors contributing to increase in the demand were outlined. Tables were presented showing the import figures for major food items.

We should use the import data not as the total of demand but as the part needed to achieve self-sufficiency. Table 1 shows the total amounts of wheat, sugar, meat, and milk imported for the whole Middle East. This table is taken from Table 10 in [12]. As mentioned the estimates in Table 1 for the rate of growth of imports will be used to generate goals for the future. Table 2 shows the estimated projected production needed to achieve self-sufficiency in future years. These food items represent aggregate categories which are sufficient for our purposes in this paper. They could be refined into subitems (e.g., meat could be beef, or lamb) as desired.

TABLE 1

Food Imports (Metric Tons)

| Food Item | 1970 | 1971 | 1972 | 1973 | Average Growth Rate |
|---|---|---|---|---|---|
| Meat | 54,262 | 49,603 | 54,245 | 64,953 | 6.2% |
| Milk | 292,927 | 286,715 | 273,861 | 278,202 | -1.7% |
| Wheat | 7,143,841 | 14,518,189 | 10,030,158 | 11,294,573 | 16.4% |
| Sugar | 1,163,907 | 1,290,438 | 1,300,989 | 1,550,657 | 10% |

TABLE 2

Projected Food Imports 1985-2000 (Metric Tons)

| Food Item | 1985 | 1990 | 2000 |
|---|---|---|---|
| Meat | 130,698 | 174,904 | 313,226 |
| Milk | 237,774 | 207,859 | 175,108 |
| Wheat | 6,704,489 | 149,303,670 | 681,710,970 |
| Sugar | 4,866,626 | 7,837,750 | 20,329,104 |

## 2.2 Supply Side

The supply side is essential to determine the inputs needed to achieve the self-sufficiency or desired goals. These will be employed in resource constraints in our model. The inputs needed for food production and especially crop production are land, water, labor and capital. In this section we address the availability of each of the resources in the Middle East.

2.2.1 Land. In the Sudan are vast expanses suitable for agricultural production. Of the country's 625 million-acre territory, 200 million acres (84 million hectars) are suitable for plant cultivation, but of this only 17 million acres are used. Of the 200 million acres of arable land 120 million acres could be used for plant cultivation and about 80 million for grazing. Apart from the land which could be cultivated by irrigation there are possibilities for cultivation using rain only. The Sudan has a variety of climate conditions. For details of land availability and climatic conditions in the Sudan see [ 9 ].

2.2.2 Water Reserve. The bulk of 200 million acres receives an adequate quantity of rain which ranges from 23 mm to 1500 mm annually. The Nile makes possible permanent irrigation. There is also a sufficient underground water reserve. Irrigation from the Nile is limited to 18.5 thousand million cubic meters annually by the 1959 Nile Water Agreement with Egypt. There are also conservation projects to increase the amount of water available to the Sudan such as the Jonglei Canal. For more details see [ 9 ].

2.2.3 Manpower. Thirty-seven percent of the population, which increases by about 3% annually, is employed. The country's annual increase in the labor force, 195 thousand workers, will be enough, according to estimates, for an annual increase of 2.5-3 million acres of cultivated land as well as for meeting the labor requirements of the non-agricultural sectors. There is a problem with the shortage of skilled labor. These aggregate figures unfortunately include large numbers of unskilled workers. However, in a temporal transition process skilled workers could be imported from nearby Egypt.

2.2.4 Capital. Due to the oil boom of the seventies, some of the Middle Eastern countries have acquired vast reserves of capital, especially Kuwait and Saudi Arabia. Thus in our model capital will not be a limiting resource.

Thus all the resources needed to achieve self-sufficiency are available. An operational scheme for employing them will be addressed in the next section.

## 3.0 The Goal Programming Approach

The method of "goal programming" is to be used to model our situation (see [2], especially Vol. I, pp. 215-221). This method is particularly suitable since we have multiple goals, and even our primary goal of economic self-sufficiency is not maximization of profit. Stated differently, we consider not only isolated economic payoffs but also the vital implications of actions on the social framework, standard of living, etc. Therefore, the concept of profit maximization in classical economic theory does not provide for either a descriptive or normative model for evaluating actions and consequences. In a complex organizational environment one must balance attempts to achieve a set of objectives to the fullest possible extent against other needs in an environment of conflicting interests, incomplete information, and limited resources.

The goal programming method for multiple objective planning and analysis was invented by Charnes and Cooper [1-4], and has been employed in many multiple objective situations [5,6]. Goals set by management compete for scarce resources, and often these goals may be incommensurable. Goal programming provides an analytic method for determining trade-offs between conflicting goals, since it reduces mathematically to an equivalent programmming problem, usually of the linear programming variety. From the latter one obtains the trade-offs.

For our purposes we find sufficient generality in the goal programming formulation, as in [2], e.g.,

$$\text{Min} \sum_{i=1}^{m} w_i f_i(x_i) \quad \text{subject to} \quad x \in X \tag{3.1}$$

where $x_i$ is the ith component of the vector $x$ and $X$ is the allowable set. Each goal function $f_i(x_i)$ measures the discrepancy from a prescribed goal $g_i$ with the indicated $x_i$ choice and the prescribed $w_i$ $(\geq 0)$, specifies the weight to be assigned to the discrepancy from $g_i$ in the indicated minimization.

To sharpen the formulation in (3.1), we choose $f_i(x_i) = \left| x_i - g_i \right|$, where the vertical strokes represent absolute (numerical) value. This will allow us even the generality of goal intervals rather than merely point goals. Then we can write the model as

$$\min \sum_{i=1}^{m} w_i \left| x_i - g_i \right| \tag{3.2}$$

subject to

$$\sum_{i=1}^{m} a_{ri} x_i \leq b_r \ , \ r = 1,2,\ldots,R \ ; \quad x_i \geq 0 \ , \ i = 1,2,\ldots,m \ ;$$

wherein the set $X$ is implicitly defined by the latter two sets of inequalities.

The goal programming problem in (3.2) can be replaced by the following equivalent linear programming problem:

$$\min \sum_{i=1}^{m} (w_i^+ d_i^+ + w_i^- d_i^-) \tag{3.3}$$

subject to

$$\sum_{i=1}^{m} a_{ri} x_i \leq b_r \qquad r = 1,2,\ldots,R$$

$$x_i - d_i^+ + d_i^- = g_i$$

with

$$x_i \ , \ d_i^+ \ , \ d_i^- \geq 0 \ , \quad i = 1,2,\ldots,m \ .$$

Here the values $d_i^+$ , $d_i^- \geq 0$ measure the deviation from the goal $g_i$ which occurs with the choice of $x_i$. This is equivalent to the absolute value formulation at the minimum value for the objective function, or if an adjacent extreme point method is employed, at every basic solution, since then $d_i^+ d_i^- = 0$ , $i = 1,\ldots,m$.

## 4.0 A Dynamic Goal Programming Model For Planning Food Self-Sufficiency

We shall limit ourselves in this example of the model to consideration of possible joint collaboration between the Middle East countries of Egypt, The Sudan, Kuwait and Saudi Arabia.

Suppose now that we wish to plan to achieve self-sufficiency in the four types of food denoted by $f_1$, $f_2$, $f_3$, and $f_4$. For each food assume there is a main crop which enters into its making. We denote respectively the amounts of these crops to be produced by $y_1$, $y_2$, $y_3$, and $y_4$. To produce a crop we need land, manpower, water and capital. We denote the amounts of these respectively by $x_1$, $x_2$, $x_3$, and $x_4$.

The production of food of type $f_i$ consists of two stages. First, crop production, and then the processing of the crop into the desired food. The output of the first stage is an input to the second stage. In the second stage our inputs are crop $y_i$, manpower, and capital. We donote amounts of manpower in stage 2 by $y_5$ and capital in stage 2 by $y_6$.

We represent the possible contributions of the four countries to these stages graphically in Diagrams 1 and 2.

We shall introduce dynamics via discrete time periods t and shall be planning arcs at a horizon of time periods $t = 1,\ldots,T$ to minimize the sum of weighted deviations from goals across this horizon.

Let us now introduce the following variables:

| | |
|---|---|
| $a_{ij}$ | amount of input i needed to produce one unit of output j in stage 1, where $i = 1,2,3,4$ and $j = 1,2,3,4$. |
| $b_{ij}$ | amount of input i needed to produce one unit of output j in stage 2, where $i = 1,\ldots,6$ and $j = 1,\ldots,4$. |
| $g_i(t)$ | goal set for food i in period t, where $i = 1,\ldots,4$. |
| $f_i(t)$ | amount of production of food i in period t, where $i = 1,\ldots,4$. |

Diagram 1

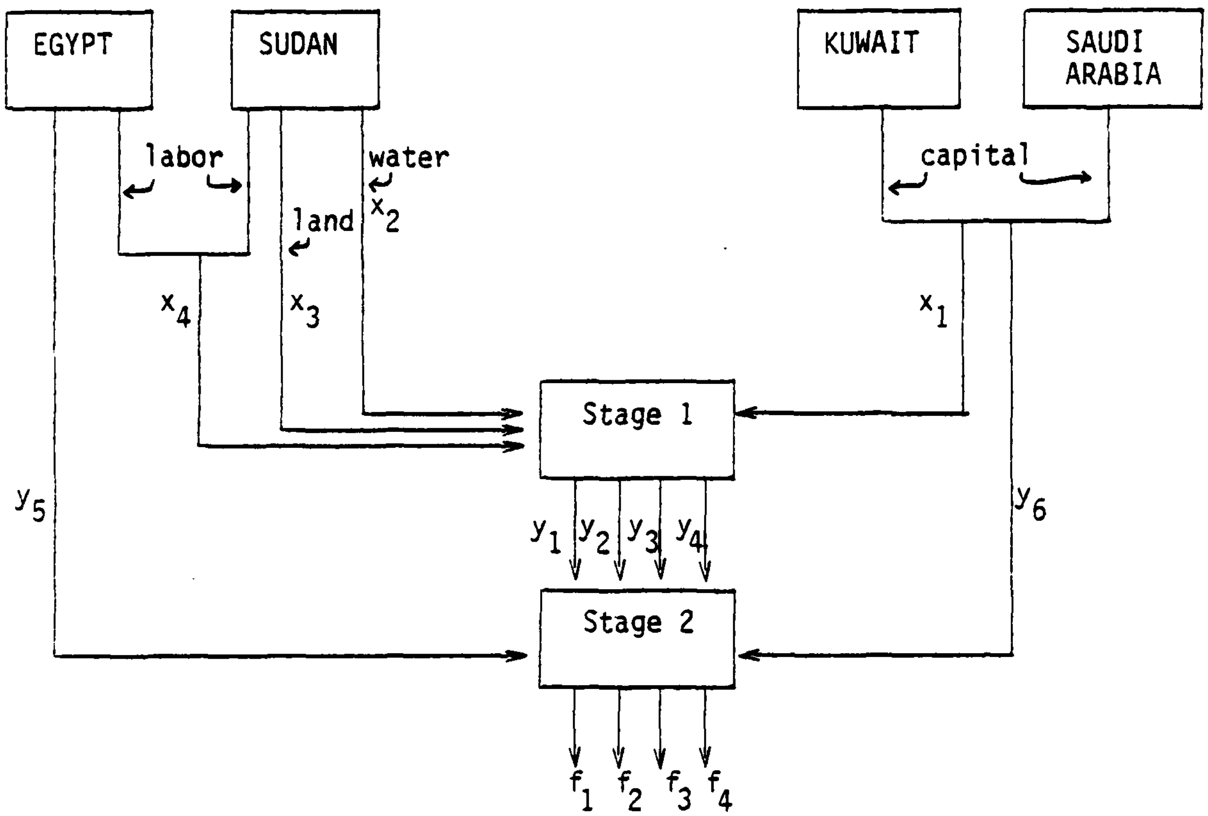
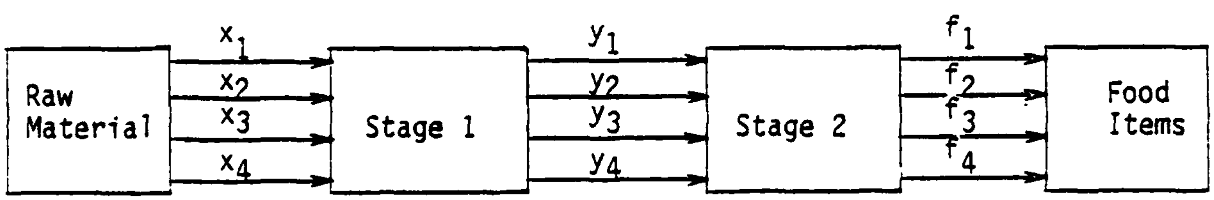



Diagram 2



$y_i(t)$ amount of output i at stage 1, where $i = 1,\ldots,4$.

$x_i(t)$ amount of inputs i at stage 1, where $i = 1,\ldots,4$.

$A_1 = (a_{ij})$, $A_2 = (b_{ij})$, are independent of time in this example model.

We have the following relations.

$A_1Y(t) = X(t)$ where $Y(t)$ is the vector of outputs and $X(t)$ is the vector of inputs in stage 1 at period t. (4.1)

$A_2F(t) = Y(t)$ where $F(t)$ is the vector of food production at period t. (4.2)

Then we have

$$A_1A_2F(t) = A_1Y(t) = X(t). \tag{4.3}$$

Let $A_1A_2 = A$, then $AF(t) = X(t)$.

We also suppose that our input amounts per period are limited (some limits may be infinity) so that $X(t) \leqslant b(t)$. Then our model is

$$\min \sum_{i=1}^{4} \sum_{1}^{T} w_i(t)|g_i(t) - f_i(t)| \tag{4.4}$$

subject to

$$AF(t) - X(t) = 0$$

$$0 \leqslant X(t) \leqslant b(t),\ F(t) \geqslant 0$$

Note that in this example for simplicity the constants from period to period are independent of one another. In other examples this may not be the case. Thus <u>here</u> we may independently solve

$$\min \sum_{i=1}^{4} w_i(t_o)|g_i(t_o) - f_i(t_o)| \tag{4.6}$$

subject to

$$AF(t\ ) - X(t\ ) = 0$$

$$0 \leq X(t_o) \leq u_o$$

Then we update our goal and we solve

$$\min \sum_{i=1}^{4} w_i |g_i(t_1) - f_i(t_1)| \tag{4.7}$$

subject to

$$AF(t\ ) - X(t\ ) = 0$$

$$0 \leq X(t_1) \leq u_1,\ F(t_1) \geq 0$$

The problem in (4.5) or (4.6) can be transformed into an equivalent linear programming problem as in (3.3) and solved for each horizon.

## 5.0 Fair Allocation of Return

One of the essential matters in joint investments is the fair allocation of the returns. It is very important to note that in our situation besides the monetary returns, which are important, there are other returns which are not directly quantifiable. For example, the countries which are participating in this joint investment will reap infra structure and social development. This might be in the countries where investment is undertaken. Also, development will aid in the political stability and avoid dependency on far away imported food.

Mainly in this section we will address the question of allocating the outputs of the investments either in terms of units of food or in terms of monetary value. This problem is not very easy due to the fact that in obtaining these outputs we need inputs from each country which are not of the same type. For example, capital and water are essential in producing food. It is very hard to compare a unit of water with a unit of capital in determining how much to allocate to the country which provides the water or the one which provides the capital. The same holds for capital versus land, land versus water and so on.

We will address the question of fair allocation by formulating the problem in a game theoretic context. This game will be in a chance-constrained characteristic function form. By that we mean the function which expresses the contribution of each player is a random variable. This is inherent in our situation due to the fact that our outputs are weather dependent.

In our example we have four countries participating in this investment; The Sudan supplying water, land and labor, Saudi Arabia and Kuwait supplying capital and Egypt supplying labor.

Instead of formulating the game in terms of the countries as players we define our game from the inputs provided by the countries. We associate with each country a meta player or meta players. Then using the optimal solution of a goal programming problem we derive a deterministic game in characteristic function form and we solve this game. The proportions accruing to each player in this game will be used to allocate the random harvest.

The following is the deterministic meta game derived from the optimal solution of the goal programming model at period t. Let capital, water, land and manpower be as player 1, player 2, player 3 and player 4, respectively, in this game.

Let $P_i(t)$ be the price of food item i in period t, where $i = 1,\ldots,4$.

$r_1(t)$ be the return (interest rate) in the period t (independent of participation in these projects).

$r_i(t)$ be the price (return on a unit) of input i in period t, where $i = 2,\ldots,4$.

We formulate the characteristic function for period t as:

$$V_t(1,2,3,4) = \sum_{i=1}^{4} P_i(t) f_i^*(t) \tag{5.1}$$

$$V_t(1) \quad = r_1(t) X_i^*(t)$$

$$V_t(i) \quad = r_i X_i^*(t) \qquad i=2,3,4$$

$$V_t(i,j) \quad = V_t(i) + V_t(j)$$

$$V_t(i,j,k) = V_t(i) + V_t(j) + V_t(k)$$

Where $x_i^*(t)$, $f_i^*(t)$ are optimal inputs and outputs for the goal programming model in period t.

One reason the realized outputs and the inputs due to chance error may be different from the one given by the optimal solution due to many factors, such as weather, human error, the nature of the estimated input-output matrix, etc., but the game in (5.1) gives us a way to distribute the random output.

If we let V be the value of the random output when realized, then from (5.1) the contribution $c_t(i)$ of input i to the grand coalition is given by

$$c_t(i) = V_t(1,2,3,4) - V_t(r,j,k) \tag{5.2}$$

$$= V_t(1,2,3,4) - V_t((1,2,3,4)-i)$$

We define meta player i's proportional (ratio) share in the realized output as:

$$S_t(i) = \frac{c_t(i)}{\sum_{i=1}^{4} c_t(i)} \tag{5.3}$$

and his monetary share $z_t(i)$ of the realized output

$$V_t \text{ is } z_t(i) = S_t(i) \cdot V_t \tag{5.4}$$

Now we return to the original game to allocate each country's share. Player 1 is capital; it is a meta player for Kuwait and Saudi Arabia. The share of meta player 1 will be divided between Kuwait and Saudi Arabia in the ratio of the amounts of capital supplied by each country. Manpower is meta player 4; its share $S_t(4)$ will be divided between Egypt and Sudan in the ration of their inputs in manpower. Water and Land are meta players 2 and 3; their share will go to the Sudan since it is the sole supplier of water and land.

## 6.0 Numerical Example

This example is intended to exhibit characteristics of the model of Section 4. We suppose the goals are to get self sufficiency in flour, sugar, milk and meat. Flour has the top priority. This is taken care of in the objective function by a high weight. Sugar has second priority, meat has third priority and milk has the least priority. We assume there is only one crop as major input to each food. For example, wheat is the major crop for flour, etc.

The following are the input output matrices for Stage 1 and Stage 2. The unit for land is acres, for water acre/feet, for capital dollars and for labor man years. The units for outputs are metric ton. The input output matrix for Stage 1:

| Inputs | Outputs | | | | | |
|---|---|---|---|---|---|---|
| | Wheat | Sugar Cane | Meat | Milk | Labor | Capital |
| capital | 20 | 25 | 15 | 15 | 150 | 1 |
| water | 103 | .05 | .005 | .004 | 0 | 0 |
| land | 0.6 | 0.015 | 0.035 | 0.03 | 0 | 0 |
| labor | 0.1 | 0.2 | 0.02 | 0.02 | 1 | 0 |

The matrix for Stage 2 is

| Inputs | Outputs | | | |
|---|---|---|---|---|
| | $f_1$(flour) | $f_2$(sugar) | $f_3$(meat) | $f_4$(milk) |
| wheat | 1.2 | | | |
| sugar cane | | 1.0 | | |
| milk | | | .2 | |
| meat | | | | 12 |
| labor | .005 | .004 | .002 | .003 |
| capital | 10 | 15 | 5 | 20 |

$A = A_1A_2$ is given by

| Inputs | Outputs | | | |
|---|---|---|---|---|
| | $f_1$ | $f_2$ | $f_3$ | $f_4$ |
| capital | 34.75 | 18.1 | 8.3 | 200.45 |
| water | 0.036 | .005 | .001 | 0.048 |
| land | 0.792 | 0.015 | 0.007 | .36 |
| labor | 0.125 | 0.024 | 0.006 | 0.243 |

The projections in table 2 are used as goals for each horizon and reasonable upper bounds are used. Different weights are given to each food. Wheat is given the highest weight of four due to its importance as a major factor in the food diet in the middle east. Sugar is given a weight of 3, meat a weight of 2 and milk a weight of 1.

The prototype model becomes as follows

$$\text{Minimize}\quad 4(P_1+N_1) + 3(P_2+N_2) + 2(P_3+N_3) + (P_4+N_4) \tag{6.1}$$

subject to

$$\begin{array}{lllllll}
34.75f_1 & + 18.1f_2 & + 8.3f_3 & + 200.45f_4 & - x_1 & & = 0 \\
0.036f_1 & + .005f_2 & + 0.001f_3 & + 0.048f_4 & - x_2 & & = 0 \\
0.792f_1 & + 0.015f_2 & + .007f_3 & + 0.036f_4 & - x_3 & & = 0 \\
0.125f_1 & + 0.024f_2 & + 0.006f_3 & + 0.243f_4 & - x_4 & & = 0 \\
f_1 & & & & & +P_1 - N_1 & = 6{,}704 \\
 & f_2 & & & & +P_2 - N_2 & = 4{,}867 \\
 & & f_3 & & & +P_3 - N_3 & = 238 \\
 & & & f_4 & & +P_4 - N_4 & = 140
\end{array}$$

$$0 \leq x_1 \leq 10000000,\quad 0 \leq x_i \leq 1000000,\quad i=2,3,4,\quad f_i \geq 0,\ N_i \geq 0,\ P_i \geq 0$$

The optimal solution for the example in (6.1) gives the level of inputs needed to achieve self-sufficiency. The amounts of inputs needed for this hypothetical example are:

capital = \$1393385.7, water = 332.9 acre/feet,

land = 2561.96 acre, labor = 1681.5 man/year.

This model if solved for each horizon will give the amounts that must be prepared in that horizon to achieve self-sufficiency.

In order to test the allocation part of the model, we generate the characteristic function defined in (5.1). We assume the price of a metric ton of wheat is \$250, the price of a metric ton of sugar is \$1500, the price of a metric ton of dried milk is \$300 and the price of a metric ton of meat is \$3000. The return on capital is 10% and lease for an acre foot water for a year is $300. The land lease per year is $200 and wage for a man/year is $1200.

The characteristic function for the meta game "played by" capital, water, land and labor is given as

$v_t(1) = (1393385.7)(0.1) = 139338.57$

$v_t(2) = (332.9)(300) = 99870$

$v_t(3) = (2561.96)(200) = 512392$

$v_t(4) = (1681.5)(1200) = 2017800$

$v_t(i,j) = V_t(i) + V_t(j)$

$v_t(1,2,3) = 751600.57$

$v_t(1,2,4) = 2257008.57$

$v_t(1,3,4) = 2669530.57$

$v_t(2,3,4) = 2630062.$

$v_t(1,2,3,4) = 250(6704) + 1500(4867) + 300(238) + 5000(140) = 9{,}467{,}900$

The contribution of meta player i is

$c_t(i) = V_t(1,2,3,4) - V_t((1,2,3,4) - i)$

$c_t(1) = 6{,}837{,}838$ $\quad$ $c_t(2) = 6{,}798{,}369.43$

$c_t(3) = 7{,}210{,}891.43$ $\quad$ $c_t(4) = 8{,}716{,}299.43$

$$s_t(i) = \frac{c_t(i)}{\sum_{i=1}^{4} c_t(i)}, \qquad \sum_{i=1}^{4} c_t(i) = 29{,}563{,}398.29$$

$s_t(1) = 0.231294045$ $\quad$ $s_t(2) = 0.229958977$

$s_t(3) = 0.243912805$ $\quad$ $s_t(4) = 0.294834142$

Suppose the realized output amounted to $15,000,000, then the capital contributors get

$$z_t(1) = (0.231294045)(15{,}000{,}000) = \$3{,}469{,}410.69$$

which is double the amount given by the characteristic function. The water contributor gets

$$z_t(2) = (0.229958997)(15{,}000{,}000) = \$3{,}449{,}384.96$$

The land contributor gets

$$z_t(3) = (0.243912806)(15{,}000{,}000) = \$3{,}658{,}692.09$$

The labor contributors get

$$z_t(4) = (0.294834142)(15{,}000{,}000) = \$4{,}422{,}512.14$$

This example shows that the value for the characteristic function is very high, which demonstrates the need and the incentive for joint cooperation. This means that the countries need to join in this investment to achieve self-sufficiency, which means that players with high contribution and more power achieved higher monetary return. The allocation given by the Scheme in Section 5 are equitable in the case of this example. The returns for all participants are so high which demonstrates the need for this joint investment.

## 6.1 Conclusion

This model is a foundation and the simplest for planning joint investments in the Middle East to achieve self-sufficiency in food items. More data is needed to test the model and the allocation plan suggested in this paper. This model will generate the mix of land, water, labor and capital to achieve self-sufficiency or be as close as possible to it, but it needs to be refined to take care of pre-investments to prepare the adequate infra structure in the Sudan. Also, it needs to be refined to link availability of inputs from horizon to horizon or period to period. These issues will be addressed in a subsequent paper and on-going research.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This study proposes a dynamic goal programming model for planning joint investment in agriculture to achieve self-sufficiency in food production in the Middle East. The issue of equitable allocation of returns to participants in the joint investments is addressed as well. Equitable divisions of profits and equitable assessment of costs to collaborating investors are developed through an associated characteristic function game.

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